UNIVERSITI PUTRA MALAYSIA

DESIGN AND DEVELOPMENT OF 1064nm Nd: YAG LASER FROM 808nm DIODE LASER SOURCE

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Master of Science

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DEDICATION

I dedicate this dissertation to:

my late m*other*

Abstract of thesis presented to the Senate of Universiti Putra Malaysia, in fulfilment of the requirement for the degree of Master of Science

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Chairman: Samsul Bahari B. Mohd. Noor, PhD

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Laser technology plays a crucial role in our every day life; in fact, it opens to us new windows and interesting horizon of science. In this respect, Nd:YAG is a crystal which is used as a lasing medium for solid-state lasers. Nd:YAG lasers typically emit light with a wavelength of 1064 nm in the infrared. However, there are also transitions near 940, 1120, 1320, and 1440 nm. Nd:YAG lasers operate in both pulsed and continuous mode. In this master thesis project, a solid-state Nd:YAG laser using diode laser source was built. The project consisted of two parts. The first part is based on a mathematical simulation using a MATLAB modelling. The target of this simulation was to determine graphs for the particles population in multiple gain media like the four-layer Nd:YAG laser, and some environmental coefficients were also incorporated in this modelling. The differential equations describe the

population of electrons in the according energy level of the Nd:YAG. They also show the output intensity of the laser. The obtained graphs described the population inversion in the energy levels inside of the Nd:YAG. The characteristics of the intensity output of the laser, during the transient time, can not be monitored by the experimental setup, therefore this was done through the MATLAB simulation. In the second part, a CW diode-pumped solid-state laser was constructed. As a laser gain medium, a Nd:YAG crystal with 1% Nd doped, lased at 1064nm, was used. 1 Watt L808P1WJ diode laser, with thermoelectric cooler, was used to excite the Nd-YAG rod. The Nd:YAG is still very inefficient in the conversion of input energy, typically the Nd:YAG lasers which are found to achieve only 5 to 10% efficiency. Light from the pump laser is generated by the laser diode driver (thorlab PRO 800- with LDC & TEC). The dimension of the Nd-YAG was 5mm diameter x 5mm length, while the mirror property of HT>99.9% @ 808nm and R>95 @ 1064nm was used. The Monochromator was used to detect the output wavelength of the laser produced. An electrical efficiency of 10.67 % was realized. The optical to optical efficiency is 19.2, with the slope efficiency of 20.2%. Although the optical to optical efficiency and slope efficiency were rather low, the electrical efficiency was considerable.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia, bagi memenuhi keperluan Ijazah Sarjana Sains.

REKABENTUK DAN PEMBENTUKAN LASER 1064nm Nd:YAG DARI LASER DIOD 808 nm

Oleh

MOHAMMADREZA SHOKRANI

Mei 2009

Pengerusi: **Samsul Bahari B. Mohd. Noor, PhD**

Fakulti: **Kejuruteraan**

Laser teknologi memainkan peranan penting dalam kehidupan harian kita. Sebenarnya ia telah membuka pemikiran manusia terhadap sains. Nd:YAG merupakan sejenis kristal yang diguanakan sebagai medium laser untuk laser yang berkeadaan pepejal. Biasanya, laser Nd:YAG merupakan cahaya yang memancarkan gelombang sepanjang 1064 nm, dalam infrared. Walaubagaimanapun, ia juga boleh mengalami perubahan sedekat 940, 1120 1320 dan 1440 nm. Nd:YAG laser boleh dioperasikan dalam tempoh pendek atau berterusan. Dalam tesis projek master ini, Nd:YAG laser yang berkeadaan pepejal telah dibina dengan menggunakan sumber diode laser. Projek ini telah dibahagikan kepada dua bahagian. Bahagian pertama adalah menggunakan matematik simulasi berdasarkan permodelan MATLAB. Tujuan simulasi adalah untuk mendapatkan populasi zarah dalam media seperti

media empat lapisan Hd:YAG laser dan koefisien alam sekitar juga dimasukkan dalam permodelan ini. Persamaan menggambarkan populasi elektron dengan mengikut aras tenaga Nd:YAG yang berlainan. Ia juga menunjukkan intensiti keluaran laser tersebut. Graf yang didapati menujukkan songsangan populasi dalam aras tenaga Nd:YAG. Ciri keluaran laser ketika dalam tempoh perubahan tidak dapat diperhatikan melalui eksperimen. Oleh itu, ianya dilakukan menggunakan MATLAB. Dalam bahagian kedua, laser keadaan pepejal pam-diod CW dihasilkan. Untuk menjadikan laser sebagai medium gandaan laser, Nd:YAG kristal dengan 1% Nd yang dilaserkan pada 1064nm telah digunakan. 1 Watt L808P1WJ laser diod dengan mesin penyejukkan termoelektrik diguanakan untuk memancarkan tiub Nd-YAG. Nd:YAG masih kurang cekap dalam menukarkan tenaga. Umumnya efisiensi yang dicapai Nd:YAG lasers hanya 5%-10%. Cahaya dari laser pam adalah dari pemacu diode laser (thorlab PRO 800-dengan LDC &TEC). Dimensi Nd-YAG adalah 5 mm garis pusat x 5mm panjang dan cermin sebagai HT>99.9% @808 nm dan R>95@ 1064nm juga digunakan. Alat Monochromator digunakan untuk mengesan panjang gelombang keluaran laser. 10.67% efisiensi dalam elektrik telah diperolehi. Efisiensi cahaya optik kepada optik efisiensi adalah 19.2 dengan kecerunan efisiensi sebanyak 20.2%. Walaupun kecekapan cahaya kepada cahaya optik dan kecekapan kecerunan masih rendah, namun kecekapan elektrik masih boleh diterima.

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I certify that a Thesis Examination Committee has met on 28 May 2009 to conduct the final examination of Mohammadreza Shokrani on his thesis entitled "Design and Development of 1064nm Nd:YAG Laser from 808nm Diode Laser Source" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Date: **16 October 2009**

DECLARATION

I declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or at any other institution.

MOHAMMADREZA SHOKRANI

Date: 26/oct/2009

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Since the concept behind this research is based on atomic radiation and laser theory, some fundamental issues are focused on, even though the complete description of solid-state laser theory is out of this thesis scope. Therefore, some of the principles related to the interaction of radiation with matter are necessary in order to understand the implementation of a laser.

Atomic systems consisting of atoms, ions, and molecules can exist only in discrete energy states. An alteration from one energy state to another, known as a transition, is related to either the emission or the absorption of a photon [5, 17, 33]. The wavelength of the absorbed or emitted radiation is given by Bohr's frequency relation:

$$E_2 - E_1 = hv_{21} \tag{1.1}$$

Where E_2 and E_1 are two discrete energy levels, v_{21} is the frequency, and h is the Planck's constant. An electromagnetic wave, with the frequency of v_{21}, corresponds to an energy gap of such an atomic system can interact with it. As for the approximation required in this respect, a solid-state material can be noted as an ensemble of many identical atomic systems. At the thermal equilibrium, the lower energy states in the material are more heavily populated than the higher energy states. A wave interacting with the substance can raise the atoms or molecules, from lower to higher energy levels and experience absorption takes place [5, 17, 33].

It is important to note that the operation of a laser requires that the energy equilibrium of a laser material be altered in such a way that energy is stored in the atoms, ions, or molecules of this material. This is achieved by an external pump source which transfers electrons from a lower energy level to a higher one. The pump radiation results in a “population inversion.”

An electromagnetic wave of p frequency, i.e. an incident on the “inverted” laser material, is amplified due to the incident photons which lead to the atoms in the higher level to drop to a lower level and hence emit additional photons. As a result, energy is exited from the atomic system and supplied to the radiation field. The emission of the stored energy is based on the stimulated or induced emission which interacts with an electromagnetic wave. In short, the material will be able to amplify the radiation at the frequency corresponding to the energy level difference, while a substance provides more atoms or even molecules in a higher energy level than in some lower levels. The acronym “laser” derives its name from this process: “Light Amplification by Stimulated Emission of Radiation” [5, 17, 33].

A quantum mechanical treatment of the interaction between radiation and matter demonstrates that the stimulated emission is, in fact, completely indistinguishable from the stimulating radiation field. This means that the stimulated radiation has the same directional properties, polarization, phase, and even spectral characteristics just like the stimulating emission. These facts are responsible for the extremely high degree of coherence, which characterizes the emission from the lasers. The fundamental nature of the induced or stimulated emission process has already been described by Einstein and Planck [5, 17, 33].

In the solid-state lasers, on the contrary, the energy levels and the associated transition frequencies are the results of different quantum energy levels or allowed quantum states of the electrons orbiting about the nuclei of atoms. In addition, to the electronic transitions, multi-atom molecules in gases exhibit energy levels that arise from the vibration-based and rotational motions of the molecule as a whole [5, 17, 33].

As the most abstract method, the three main photonic transactions shown are found to take place in materials (Figure 1.1):

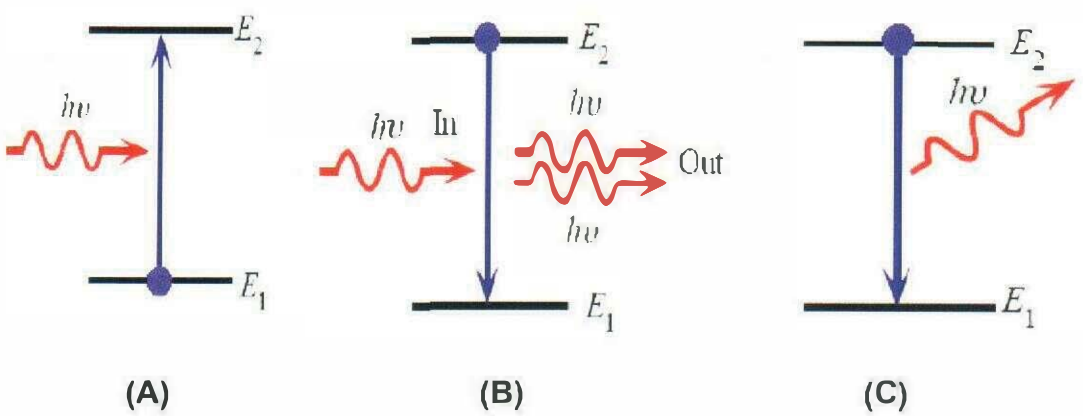

Figure1.1 (A) Absorption (B) Stimulated Emission (C) Spontaneous Emission

An atom absorbs a photon (A), which excites it for a while, the photon is later spontaneously emitted (C), A second photon can stimulate the atom to emit in a time shorter than the spontaneous lifetime (B)

1.2 Aims and Objectives

This research has two major parts; the first one is based on the MATLAB modelling, while the second part is completely experimental. The whole aims of this research are as follows:

i. Creating a mathematical modelling using MATLAB for the Nd:YAG population inversion and output laser intensity.

ii. Designing and developing a 1064 nm Nd:YAG laser from 808nm diode laser source.

In the section on modelling, the model of a semi-conductor diode pumped Nd:YAG crystal was used to simulate the characteristics which are very close to real ones. The modelling of the system is to write the differential equations which will model the system. In particular, these equations account for the energy in the atoms of the crystal and the feedback provided by cavity. They are an accurate model of the laser system used. These differential equations describe the population of the electrons according to the energy level of the system. Meanwhile, the output intensity of the laser is also provided by these equations. Nevertheless, the characteristics of the output of the laser during the transient time can not be monitored during the experiment. For this reason, the MATLAB simulation is used to monitor them and the population of the electrons in each level.

In the second part, the laboratory setup was assembled in order to realize the emission and absorption effects in the Diode Pumped Nd:YAG-Laser, which were sandwiched between reflective laser mirrors, after diagnosing the attributes of the setup. The 1064nm output power, produced by 808nm diode laser source, was obtained and the result was recorded as the output power in relation to the pump power, slope efficiency, optical to optical efficiency and electrical efficiency. Similarly, the characteristics of the laser output were achieved by changing the temperature, etc., in the attempt to increase the efficiency of the whole system.

Finally, the laser diode was also replaced with high power light emitting diodes to determine the effects of the changes. Thus, it is so clear that replacing a few Euros high power LEDs, instead of multi thousand Euros laser diode, would be advantageous from the economic point of view.

1.3 Scope of Work

The study attempted to realize the parametric analysis of Nd:YAG laser, and for this purpose, the MATLAB mathematical modelling was implemented. These comments and methods are therefore discussed.

It is important to note that using circular (recursive) ordinary differential equivalent functions are rather complicated in the MATLAB mathematical modelling. Thus, a good level of familiarity with the (Ordinary Differential Equation) ODE function in the MATLAB is necessary in order to understand this section better.

The figures for the results derived from the MATLAB were implemented in different essential conditions in this research and these are also discussed. Each of the modules is defined and their functions are explained by discussing their operating considerations and comparing the search results which are done in the next steps.

After the desired results using laser diode as a pump for Nd:YAG crystal had been achieved, the pump device with high power light emitting diode, and lower light conjunction (beaming) was changed and used to get the setup work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides a literature review on Nd:YAG and focuses on the theory of lasing process involved in Nd:YAG laser. A short history of the Nd:YAG laser, as well as the design procedure fundamental for mathematical modelling and experimental fabrication are also given in this chapter.

2.2 Literature Review on Nd:YAG Laser

Since the invention of the vacuum amplifier tube by Lieben and Forest in 1905/06, the amplification of electromagnetic waves over a broad wavelength range and building of oscillator with such waves have been able to be generated [2, 17, 24]. This was extended into the millimetre wave region with advances in amplifier tubes and later solid-state devices such as transistors. Until the 1950s, the thermal radiation sources were mostly used to generate electromagnetic waves in the optical frequency range [17, 24]. The generation of coherent optical waves was only made possible by the Laser. The first amplifier, based on discrete energy levels (quantum amplifier), was the MASER (Microwave Amplification by Stimulated Emission of Radiation), which was invented by Gordon, Townes and Zeiger in 1954. In 1958, Schawlow and Townes proposed to extend the principle of MASER to the optical regime [21, 33, 34].

The amplification should arise from the stimulated emission between discrete energy levels which must be inverted, as discussed in the final section. The amplifiers and oscillators based on this principle are called LASER (Light Amplification by Stimulated Emission of Radiation). Maiman was the first to demonstrate laser based on the solid-state laser material Ruby (Figure 2.1) [5].

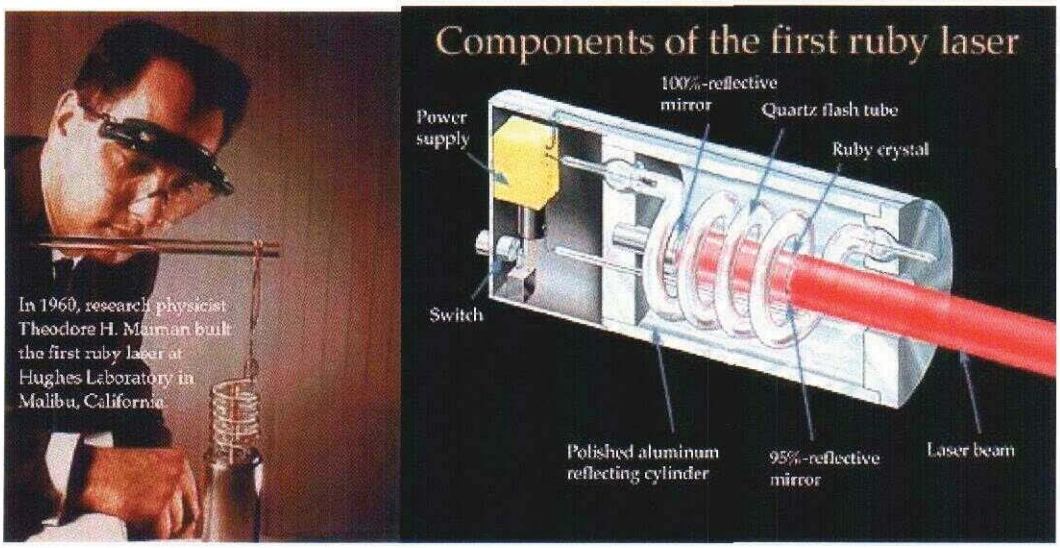

Figure 2.1 Theodore Maiman with the first Ruby Laser in 1960 and a cross sectional view of the first device [5]

Meanwhile, the first HeNe-Laser, a gas laser followed in 1961. It was the gas laser which was built by Ali Javan at (Massachusetts Institute of Technology) MIT, with a wavelength of 632.8 nm, and a line width of only 10 kHz [2]. Thereafter, more professional items are needed to to be presented in order to achieve a better understanding. Meanwhile, the most important point in this